ELECTRON ACCELERATION IN THE WAKE FIELD EXCITED BY 200TW FEMTO SECOND LASER IN UNDERDENSE PLASMA

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Abstract

Laser-plasma acceleration experiment has been carried out using 200TW, 30fs Ti:Sapphire laser pulses focused on helium gas-jets with F/8.75 optics. Intense mono-energetic electron beams have been produced by controlling plasma length and density precisely. Energy spectral oscillations of accelerated electrons in respect to ejection angle have been also observed. Measurement of images from Thomson scattering and fluorescence side scattering from plasma indicate highly relativistic effects such as a long self-channeling and filamentation. It seems that these nonlinear phenomena strongly disturb high energy gain acceleration and high quality beam generation.

INTRODUCTION

Wake-field acceleration including plasma beat wave, plasma wake-field and laser wake-field acceleration has been studied to take advantage of high acceleration gradient which promises a compact accelerator. Recently good quality and high energy electrons have been demonstrated based on laser wake-field acceleration [1-3]. The recent development of laser technology enables us to use ultra-high power and short pulse lasers which can excite a large amplitude plasma wave. Electron motion in large amplitude plasma is involved in nonlinear dynamics. It has been studied theoretically and in particle-in-cell simulations [4,5], however, not well demonstrated experimentally yet. Here we present the results of electron acceleration in the nonlinear plasma wave excited by 200 TW femto second pulses.

EXPERIMENTAL SETUP

The experiment was performed with Ti:Sapphire laser system "SILEX-1" at CAEP [6]. The laser pulses of 800 nm wave length and 30 fs duration with 4 - 8.3 J were focused with F/8.75 optics onto helium gas-jets. The laser spot radius, w_0, was 12 μm, which yields peak intensity up to 1.8 – 3.8×10^{19} W/cm^2 and the laser strength parameter, a_0, up to 2.9 – 3.8 on assumption that the energy concentration is 30%. The laser was polarized in horizontal axis. The experimental setup for electron energy measurements is shown in Fig. 1. Thomson scattering images from plasma were recorded by a charge-coupled device, CCD, camera (CCD1) which was set on top of a gas-jet applying a band-pass filter with the wave range of 800 nm ± 10 nm in front of the CCD camera. Fluorescence side scattering images were also monitored by a CCD camera (CCD2) followed by a band-pass filter with the wave range of 400 nm ± 10 nm. Accelerated electrons were momentum analyzed using a permanent magnet, a phosphor screen, DRZ, placed just after the exit of the magnet, and a CCD camera (CCD3). Backward Raman scattering was measured by an optical multi-channel analyzer (OMA) system.

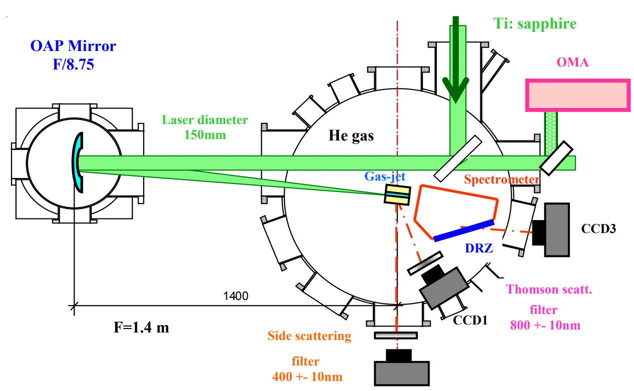

Figure 1: Schematic layout of the experimental setup for electron energy measurements.

Helium gas-get nozzles

We used two kinds of nozzles shown in Fig. 2(a) and (b) to adjust the plasma lengths. The nozzle in (a) is a supersonic Laval nozzle [7] which has a rectangular slit

10 mm in length and 1.2 mm in width. The nozzle in (b) is a conical nozzle which has a ϕ5 mm aperture at exit and a ϕ1 mm aperture at entrance. The nozzle in (a) was set in such a way the main laser went through the 10 mm side of the slit in order to produce longer plasma channels.

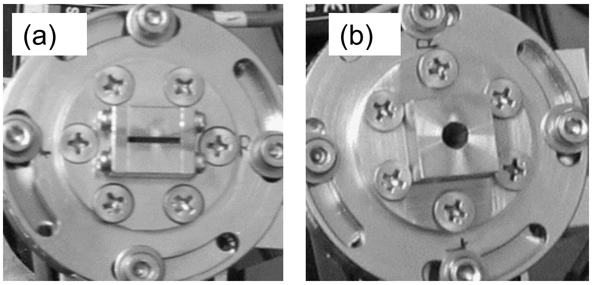

Figure 2: (a) Supersonic Laval nozzle with a slit 10 mm in length and 1.2 mm in width. (b) ϕ5 mm conical nozzle.

RESULTS

Electron acceleration with Laval nozzle

High intense electron beam was generated when the laser power was 202 TW, a_0 = 3.5, and plasma density was approximately $1\times10^{19}/cm^3$. The energy spectrum is shown in Fig. 3. The peak energy is 34 MeV. The spectrum has three lines which are separated vertically from each other. The upper and middle lines in the spectrum bend down as the energy becomes higher. At the end of these lines, there are two high mono-energy parts at 131 MeV as shown in Fig.3 (b). Figure 4(a) and (b) show Thomson scattering and fluorescence side scattering images, respectively. The laser was injected from the left side of the figures. In Fig. 4(a), a discontinuous bright line having a fine spot structure reaches to 4.7 mm long. This image shows a long self-channeling of laser in plasma involving relativistic focusing and ponderomotive channeling [8]. In Fig. 4(b), there is a thin bright line in the middle of a channel. This line is cased by second harmonic Thomson scattering of laser due to 8 figure motion of electron in the plasma [9]. The surrounding light is caused by the recombination of plasma.

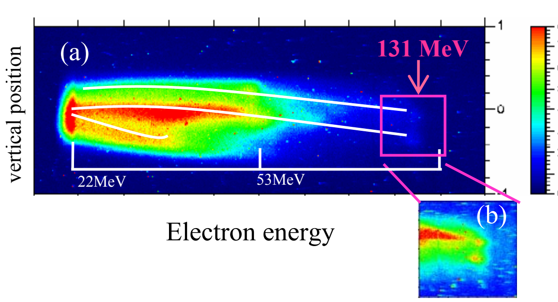

Figure 3: (a) Electron energy spectrum with 202 TW laser power, a0 = 3.5 and plasma density around $1\times10^{19}/cm^3$. (b) Close up view of two high mono-energy parts at 131 MeV.

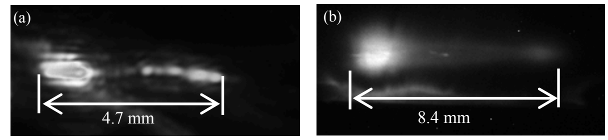

Figure 4: (a) Image of Thomson scattering from plasma. A discontinuous bright line with fine structures reaches to 4.7 mm long. (b) Image of fluorescence side scattering.

Filamentation

In addition to a long self-channeling, we observed a non linear phenomenon, filamentation [10], in Thomson scattering images when we used the supersonic laval nozzle. These images are shown in Figs. 5(a) and (b). The channels divide into two or more. In most cases when filamentaions occurred, electrons were not observed. Moreover, from the fluorescence side scattering image (not shown here) , we have found that laser propagations are shorter than those with electron. Non linear phenomena such as filamentation seem strongly disturb electron acceleration.

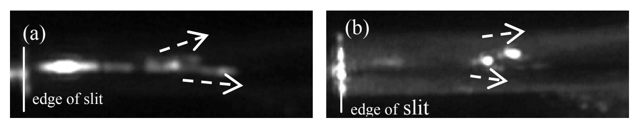

Figure 5: (a), (b) Thomson scattering images showing filamentations. The channels divide into two. The arrows are for eye-guide.

Electron acceleration with conical nozzle

To avoid filamentations and channel deflections, we optimized the plasma length using the conical nozzle shown in Fig. 2(b). In the condition that the laser axis passed through 4.5 mm long above the conical nozzle with 195 TW laser power, a_0 = 3.5 and plasma density of around $1\times10^{19}/cm^3$, mono-energetic electron beam was produced. The energy spectrum is shown in Figure 6. The mono-energetic part forms a Gaussian centred at 52.3 MeV with an energy spread of 6.3 MeV FWHM. Beam divergence is estimated to be 0.33 degrees FWHM from 3.3 mm vertical spot size on DRZ and 28 cm path length. Figure 7(a) and (b) show Thomson scattering and fluorescence side scattering images on this shot. Self-channeling continues 1.9 mm long in plasma, which implies the field gradient of 27GeV/m.

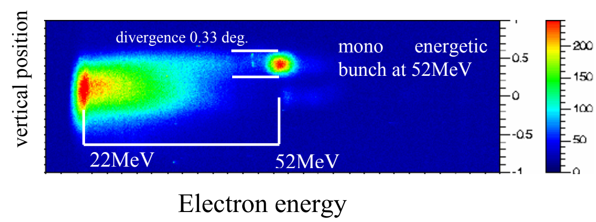

Figure 6: Electron energy spectrum with 195 TW laser power, a_0 = 3.5, and plasma density of around $1\times10^{19}/cm^3$.

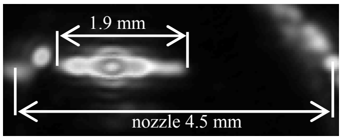

Figure 7: Image of Thomson scattering from plasma.

Energy spectrum oscillation

Figure 8 shows a electron spectrum obtained using the same conical nozzle. The laser power at this show is 224 TW and a_0 is 3.7. Vertical oscillation of electron position is clearly seen. This vertical (transverse) motion is due to wiggle trajectory of electrons in the plasma [5]. Figure 9 shows the same energy spectrum integrated over the vertical position. At this shot, electrons have been accelerated up to more than 150 MeV.

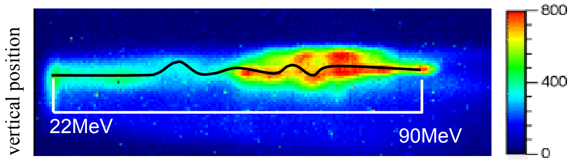

Figure 8: Electron energy spectrum with 224 TW laser power, a0 = 3.7, and plasma density of around $1\times10^{19}/cm^3$.

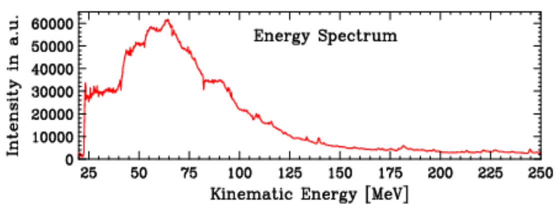

Figure 9: Electron energy spectrum with 195 TW laser power, a0 = 3.5, and plasma density of around $1\times10^{19}/cm^3$.

CONCLUSION

The laser-plasma accelerator experiment in the range of 200TW femto second pulses has been demonstrated. 52 MeV mono-energetic electron beam has been obtained controlling the plasma length and plasma density. Non-linear phenomena of laser plasma interaction, such as a long self-channeling, filamentation have been seen. Electron transverse oscillations are also measured. Filamentations may disturb the acceleration of electrons. A further analysis is in progress.

ACKNOWLEDGMENTS

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